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# Allogeneic stem cell transplantation benefits for patients $\geq 60$ years with acute myeloid leukemia and *FLT3* internal tandem duplication: a study from the Acute Leukemia Working Party of the European Society for Blood and Marrow Transplantation

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## ABSTRACT

Intermediate-risk cytogenetic acute myeloid leukemia with an internal tandem duplication of *FLT3* (*FLT3*-ITD) is associated with a high risk of relapse, and is now a standard indication for allogeneic stem cell transplantation. Nevertheless, most studies supporting this strategy have been performed in young patients. To address the benefit of allogeneic transplantation in the elderly, we made a selection from the European Society for Blood and Marrow Transplantation registry of *de novo* intermediate-risk cytogenetic acute myeloid leukemia harboring *FLT3*-ITD in patients aged 60 or over and transplanted from a related or unrelated donor between January 2000 and December 2015. Two hundred and ninety-one patients were identified. Most patients received a reduced-intensity conditioning (82%), while donors consisted of an unrelated donor in 161 (55%) patients. Two hundred and twelve patients received their transplantation in first remission, 37 in second remission and 42 in a more advanced stage of the disease. The 2-year leukemia-free survival rate was 56% in patients in first remission, 22% in those in second remission and 10% in patients with active disease, respectively ( $P < 0.005$ ). Non-relapse mortality for the entire cohort was 20%. In multivariate analysis, disease status at transplantation was the most powerful predictor of worse leukemia-free survival, graft-versus-host disease and relapse-free survival, and overall survival. In this elderly population, age was not associated with outcome. Based on the current results, allogeneic transplantation translates into a favorable outcome in fit patients  $\geq 60$  with *FLT3*-ITD acute myeloid leukemia in first remission, similarly to current treatment recommendations for younger patients.

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## Introduction

Internal tandem duplication in the juxtamembrane domain of the tyrosine kinase receptor gene *FLT3* (*FLT3*-ITD) is one of the most frequent recurrent mutations in acute myeloid leukemia (AML),<sup>1-3</sup> and translates into early relapse and worse sur-

vival in young and older AML patients with normal karyotype or other intermediate-risk cytogenetics (IRC).<sup>4,6</sup> Allogeneic stem cell transplantation (SCT), which has been shown to be beneficial in first remission (CR1) in most studies,<sup>8,7-11</sup> has emerged as the best consolidation strategy in these patients. However, the vast majority of these studies were performed in patients under 60 years of age, transplanted with a myeloablative conditioning and using a matched sibling donor, while data for SCT in patients over 60 years of age harboring *FLT3*-ITD AML in CR1, especially with a reduced-intensity conditioning (RIC) regimen, are rather limited.

The benefit of RIC SCT in AML patients with *FLT3*-ITD in CR1 has been observed in a previously reported small-scale single center study.<sup>12</sup> Howbeit, the median age in this study was 55, ranging from 19 to 64 years, which may not represent a true elderly population. In a subsequent retrospective European Society for Blood and Marrow Transplantation (EBMT) study by Schmid *et al.*, the authors confirmed the significant negative impact of *FLT3*-ITD on outcome.<sup>13</sup> Moreover, in this cohort, which included patients of up to 71 years old, advanced age was found to be a significant negative factor, associated with worse leukemia-free survival (LFS) and increased non-relapse mortality (NRM).<sup>3,13</sup> Nevertheless, the improvement in supportive care, human leukocyte antigen (HLA) typing and the development of new RIC regimens substantially reduce NRM, extend the eligibility criteria for SCT, and signify that age should no longer be a barrier to SCT.<sup>14,15</sup> Albeit, relapse remains the major cause of treatment failure with RIC regimens.<sup>16,17</sup> Due to the early relapse incidence (RI) in *FLT3*-ITD AML<sup>4</sup> and the intrinsic chemoresistance and poor tolerance to therapy in elderly patients,<sup>18</sup> the role of SCT in this older population may appear questionable. To evaluate the potential benefit of SCT in elderly patients with *FLT3*-ITD AML, we decided to conduct a retrospective study based on the EBMT registry in order to address the outcomes of *FLT3*-ITD AML in patients aged 60 or over and undergoing SCT.

## Methods

### Patient selection and data collection

Herein is a retrospective study performed by the Acute Leukemia Working Party (ALWP) of the EBMT group. The EBMT registry is a voluntary working group of more than 500 transplant centers, the participants of which are required to report all consecutive SCT and follow-up from their respective centers once a year. Patients aged 60 or over with a diagnosis of *de novo* AML transplanted between 1<sup>st</sup> January 2000 and 31<sup>st</sup> December 2015 with a related or unrelated donor (10/10 or 9/10) who were reported to the EBMT registry were included in this analysis. We selected only those patients with normal karyotype or other intermediate-risk karyotype, according to the European LeukemiaNet (ELN) classification,<sup>19,20</sup> and harboring a *FLT3*-ITD mutation at the time of diagnosis. Patients with second SCT have been excluded, as have those who underwent a cord blood or haploidentical transplantation. All patients provided informed consent for the use of their data in retrospective studies. The Review Board of the ALWP as well as the ethic committee of the EBMT approved this study. A total of 291 patients from 100 centers met the criteria and were selected for further analysis.

Myeloablative conditioning (MAC), RIC and non-myeloablative conditioning regimen (NMA) have been defined elsewhere.<sup>21</sup>

The following variables were selected and included in the analysis: year of transplantation, age, sex, white blood cell count (WBC) at diagnosis, status at transplantation, time from diagnosis to CR, time from CR to SCT, the number of induction courses to reach CR, type of conditioning regimen, *in vivo* T-cell depletion (including both anti-thymocyte globulins and alemtuzumab), cytomegalovirus (CMV) status of donor and recipient, donor type, source of stem cells, Karnofsky performance status (KPS) at transplantation, engraftment, presence of acute and chronic graft-versus-host disease (GvHD), grade of acute GvHD, and NPM1 status. The molecular remission status at the time of SCT is center-dependent and was not defined in the registry.

### Statistical analysis and endpoints definitions

Endpoints included LFS, RI, NRM, overall survival (OS), acute and chronic GvHD, and GvHD-free/relapse-free survival (GRFS). All outcomes were measured from the time of transplant. LFS was defined as survival without relapse; patients alive without relapse were censored at the time of last contact. OS was based on death from any cause. NRM was defined as death without previous relapse. GRFS was defined as survival without grade 3-4 acute GvHD, extensive chronic GvHD, relapse or death. Surviving patients were censored at the time of last contact. The probabilities of OS, LFS and GRFS were calculated by the Kaplan-Meier test, and those of acute and chronic GvHD, NRM, and relapse were determined by the cumulative incidence estimator to accommodate competing risks. Results are expressed with a 95% confidence interval (CI). For NRM, relapse was the competing risk, while for relapse the competing risk was NRM. For acute and chronic GvHD, death without the event and relapse were the competing risks.

For all prognostic analyses, continuous variables were categorized and the median was used as a cut-off point, excepting that of age which was analyzed as a continuous variable in multivariate analysis. A Cox proportional hazards model was used for multivariate regression. Factors associated with a *P*-value less than 0.15 by univariate analysis, and other clinically meaningful variables were included in the model. Results were expressed as the hazard ratio (HR) with 95% CI.

All tests were two-sided. The type-1 error rate was fixed at 0.05 for the determination of factors associated with time-to-event outcomes. Statistical analyses were performed with SPSS 19 (SPSS Inc./IBM, Armonk, NY, USA) and R 3.0.1 (R Development Core Team, Vienna, Austria) software packages.

## Results

### Patients' characteristics

Characteristics of the 291 selected patients are listed in Table 1. Median age at SCT was 63.7 years (range: 60-75.4). Only 12 patients were over 70 years old. The most frequent RIC was fludarabine and busulfan (N=118), followed by fludarabine and melphalan (N=42). Twenty-three patients, including 15 with active disease, one in second complete remission (CR2) and seven in CR1, received a fludarabine, amsacrine, and cytarabine (FLAMSA)-RIC preparative regimen.<sup>22</sup> *In vivo* T-cell depletion (TCD) included 162 patients with anti-thymocyte globulins and 35 patients with alemtuzumab. At the time of SCT, most patients (252, 94%) had a KPS of more than 80%, and 71% had more than 90%. The characteristics of CR1 patients are summarized in Table 2. Molecular status at the time of SCT was available for 104 out of 202 CR1 patients; 80 (77%) were in molecular CR1.

### Engraftment and graft-versus-host disease

Engraftment was successful in 268 patients (98%) with a median time to neutrophils engraftment of 17 days (range: 6-64). The cumulative incidence of grade II-IV acute GvHD was 22% (95% CI: 17.7-27.6) and the 2-year cumulative incidence of chronic GvHD was 34% (95% CI: 28.4-40.5) (Figure 1). The cumulative incidence of grade III-IV acute GvHD was 8% (95% CI: 5-12) and the 2-year cumulative incidence of extensive chronic GvHD was 15% (95% CI: 10.5-19.8).

In the multivariate analysis performed in the entire population, a lower performance status was associated with more grade III-IV acute GvHD (16% [95% CI: 8.2-25.2] vs.

6% [95% CI: 3.2-6.2], for patients with KPS of <90% vs. ≥90%, respectively, HR=0.4, 95% CI: 0.17-0.93,  $P=0.03$ ). The age of both the patient and donor, type of donor, source of stem cells, TCD and conditioning intensity were

**Table 1. Patient characteristics of the entire cohort.**

Patient's characteristics N=291	
Median age at SCT (range)	63.7 years old (60-75.4)
Median follow-up (range)	23 months (2-173)
WBC at diagnosis (range)	44.0 x 10 <sup>9</sup> /L (1-575)
Median year of SCT	2012 (2002-2015)
Remission status at SCT, N(%)	
CR1	212 (72.9%)
CR2	37 (12.7%)
Not in CR	42 (14.4%)
Sex, N(%)	
Male	150 (51.5%)
Female	141 (48.5%)
Donor type, N(%)	
Sibling	130 (44.7%)
Unrelated	161 (55.3%)
Cytogenetics, N(%)	
Normal	254 (87.3%)
Abnormal	37 (12.7%)
<i>NPM1</i> status, N(%)	
Unmutated	50 (24.6%)
Mutated	153 (75.4%)
Missing	88
Source of SC	
BM	27 (9.3%)
PB	264 (90.7%)
<i>In vivo</i> T-cell depletion, N(%)	197 (68.4%)
Conditioning regimen, N(%)	
MAC	52 (17.9%)
RIC	200 (68.7%)
NMA	39 (13.4%)
Karnofsky > 80%, N(%)	252 (94%)
CMV patient+, N(%)	199 (69%)
CMV donor+, N(%)	153 (53.3%)
Co-morbidity score (HCT-CI)	
0	65 (58%)
1-2	22 (19.6%)
3+	25 (22.3%)
Missing	179

N: number; SCT: stem cell transplantation; WBC: white blood cell count; CR: complete remission; SC: stem cell; BM: bone marrow; PB: peripheral blood; MAC: myeloablative conditioning; RIC: reduced-intensity conditioning; NMA: non myeloablative conditioning; CMV: cytomegalovirus; HCT-CI: hematopoietic cell transplant co-morbidity index.

**Table 2. CR1 patients' characteristics.**

Patient's characteristics N=212	
Median age at SCT (range)	63.5 years old (60-72.4)
WBC at diagnosis (range)	42.3 x 10 <sup>9</sup> /L (1-380)
Median year of SCT	2012 (2002-2015)
Interval from diagnosis to CR1 (range)	42 days (13-149)
Interval from CR1 to SCT (range)	98 days (15-300)
Interval from diagnosis to SCT (range)	5 months (2-17)
Number of induction courses to CR1, N(%)	
1	126 (73.7%)
2 or more	45 (26.3%)
Missing	41
Sex, N(%)	
Male	110 (51.9%)
Female	102 (48.1%)
Female to male, N(%)	41 (19.3%)
Donor type, N(%)	
Sibling	103 (48.6%)
Unrelated	109 (51.4%)
Cytogenetics, N(%)	
Normal	183 (86.3%)
Abnormal	29 (13.7%)
<i>NPM1</i> status, N(%)	
Unmutated	35 (23.5%)
Mutated	114 (76.5%)
Missing	63
Molecular CR at SCT	
No molecular CR	24 (23.1%)
Molecular CR	80 (76.9%)
Missing	108
Source of SC	
BM	23 (10.9%)
PB	189 (89.2%)
<i>In vivo</i> T-cell depletion, N(%)	142 (67.6%)
Conditioning regimen, N(%)	
MAC	33 (15.6%)
RIC	146 (68.9%)
NMA	33 (15.6%)
Karnofsky > 80%, N(%)	186 (96.4%)
CMV patient+, N(%)	140 (66.4%)
CMV donor+, N(%)	114 (54.3%)
Co-morbidity score (HCT-CI)	
0	47 (57.3%)
1-2	18 (22%)
3+	17 (20.7%)
Missing	130

N: number; SCT: stem cell transplantation; WBC: white blood cell count; CR1: first complete remission; SC: stem cell; BM: bone marrow; PB: peripheral blood; MAC: myeloablative conditioning; RIC: reduced-intensity conditioning; NMA: non myeloablative conditioning; CMV: cytomegalovirus; HCT-CI: hematopoietic cell transplant co-morbidity index.



not significantly associated with the incidence of acute GvHD. Focusing on the 212 patients transplanted in CR1, only a better KPS ( $>90\%$ ) at SCT correlated with less grade II-IV and grade III-IV acute GvHD (HR=0.43, 95% CI: 0.22-0.82,  $P=0.01$  and HR=0.13, 95% CI: 0.04-0.41,  $P=0.0005$ , respectively).

Regarding chronic GvHD, no correlation was observed between the cumulative incidence of chronic GvHD and age, type of donor or source of stem cells. In the multivariate analysis performed in the entire population, better KPS was associated with more overall chronic GvHD (HR=1.95, 95% CI: 1.08-3.51,  $P=0.03$ ), while TCD correlated with less overall chronic GvHD (HR=0.51, 95% CI: 0.32-0.83,  $P=0.006$ ) and less extensive chronic GvHD (HR=0.29, 95% CI: 0.14-0.59,  $P<0.001$ ). We also found significantly less extensive chronic GvHD with RIC ( $P=0.02$ ), and more extensive chronic GvHD with a female donor to a male recipient ( $P=0.02$ ). Among patients transplanted in CR1, we found a significant impact of donor's age, with a higher incidence of chronic GvHD when an older donor was used (46% [95% CI: 35-56.9] vs. 31% [95% CI: 21.5-41.7] with a donor aged  $>47$  and  $\leq 47$  years old, respectively,  $P=0.04$ ).

### Non-relapse mortality

The 2-year cumulative incidence of NRM for the whole cohort was 20% (95% CI: 15.6-25.4). In multivariate analysis, active disease at the time of SCT was significantly associated with increased NRM ( $P=0.01$ ), while unrelated donors showed a trend toward a higher NRM (Table 3, Figure 2A). Thus, 2-year NRM was 18% (95% CI: 12.8-23.9) in CR1 patients and 29% (95% CI: 15.6-43) in patients with active disease who underwent transplantation (HR=2.38, 95% CI: 1.17-4.84,  $P=0.02$ ). The presence of chronic GvHD was significantly associated with more NRM in multivariate analysis (HR=2.38, 95% CI: 1.04-5.49,  $P=0.04$ ). In patients transplanted in CR1, the interval from CR1 to SCT was significantly associated with NRM in univariate analysis, being 7% (95% CI: 2.9-14.3) for patients transplanted within 98 days from CR1 and 24% (95% CI: 15.2-33.5) for patients transplanted more than 98 days from CR1. In multivariate analysis, a 9/10 unrelated donor was significantly associated with more NRM compared to a sibling donor, whereas NRM from a 10/10 unrelated donor SCT was comparable to a sibling donor ( $P=0.03$  and  $P=0.42$ , respectively). Thus, 2-year NRM was 32% (95% CI: 12-53.8) when the SCT was performed with a 9/10 unrelated donor, 17% (95% CI: 9.7-25.3) when a sibling donor was used, and 16% (95% CI: 9.2-25.6) when the donor was a 10/10 unrelated donor. A longer interval from CR1 to SCT remained significantly associated with higher NRM in multivariate analysis ( $P=0.04$ ) (Table 4).

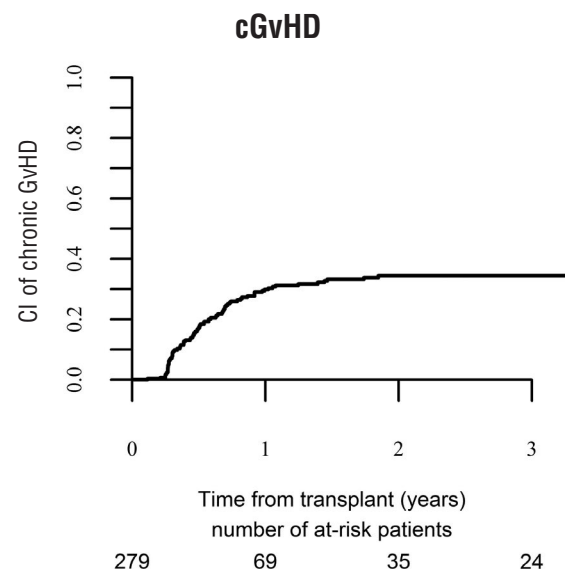
### Relapse incidence

The 2-year cumulative RI in the overall series was 35.4% (95% CI: 29.6-41.3). RI strongly correlated with disease status at the time of SCT, at 26.1% (95% CI: 19.9-32.6), 56.8% (95% CI: 37.1-72.3) and 61.9% (95% CI: 44.9-77) for patients transplanted in CR1, CR2 and not in remission at the time of SCT, respectively ( $P<0.001$ ) (Figure 2B). In multivariate analysis, both CR2 and active disease were significantly associated with increased RI compared to patients transplanted in CR1 ( $P<0.001$  and  $P<0.001$ , respectively) (Table 3). The presence of chronic

GvHD was not associated with less relapse (HR=0.96, 95% CI: 0.48-1.9,  $P=0.9$ ). Focusing on patients transplanted in CR1, a significant correlation between RI and the interval from diagnosis to CR1 ( $P=0.003$ ) was demonstrated in univariate analysis, in line with the significant association between relapse and the number of induction courses to achieve CR1 ( $P<0.001$ ). Thus, RI was 17.5% (95% CI: 10-26.9) when the interval from diagnosis to CR1 was less than 42 days, and 34.4% (95% CI: 24.1-44.9) when this interval was greater than 42 days; this difference was confirmed in multivariate analysis (HR: 2.32, 95% CI: 1.15-4.7,  $P=0.02$ ). Being in molecular remission at the time of SCT was also significantly associated with less relapse in CR1 patients (17% vs. 44%,  $P=0.001$ ). Five out of 24 patients with persistent molecular disease at the time of SCT received donor lymphocyte infusion (DLI) compared to 11 out of 80 patients with molecular remission ( $P=0.4$ ). Increasing age (as a continuous variable), NPM1 status, type of donor, and conditioning intensity did not influence RI in multivariate analysis. TCD showed a trend toward less relapse in multivariate analysis (HR=0.53, 95% CI: 0.27-1.04,  $P=0.06$ ). Molecular status at the time of SCT was not included in the multivariate analysis due to an excess of missing data ( $N=108$ ).

### Overall survival, leukemia-free survival and graft-versus-host/relapse-free survival

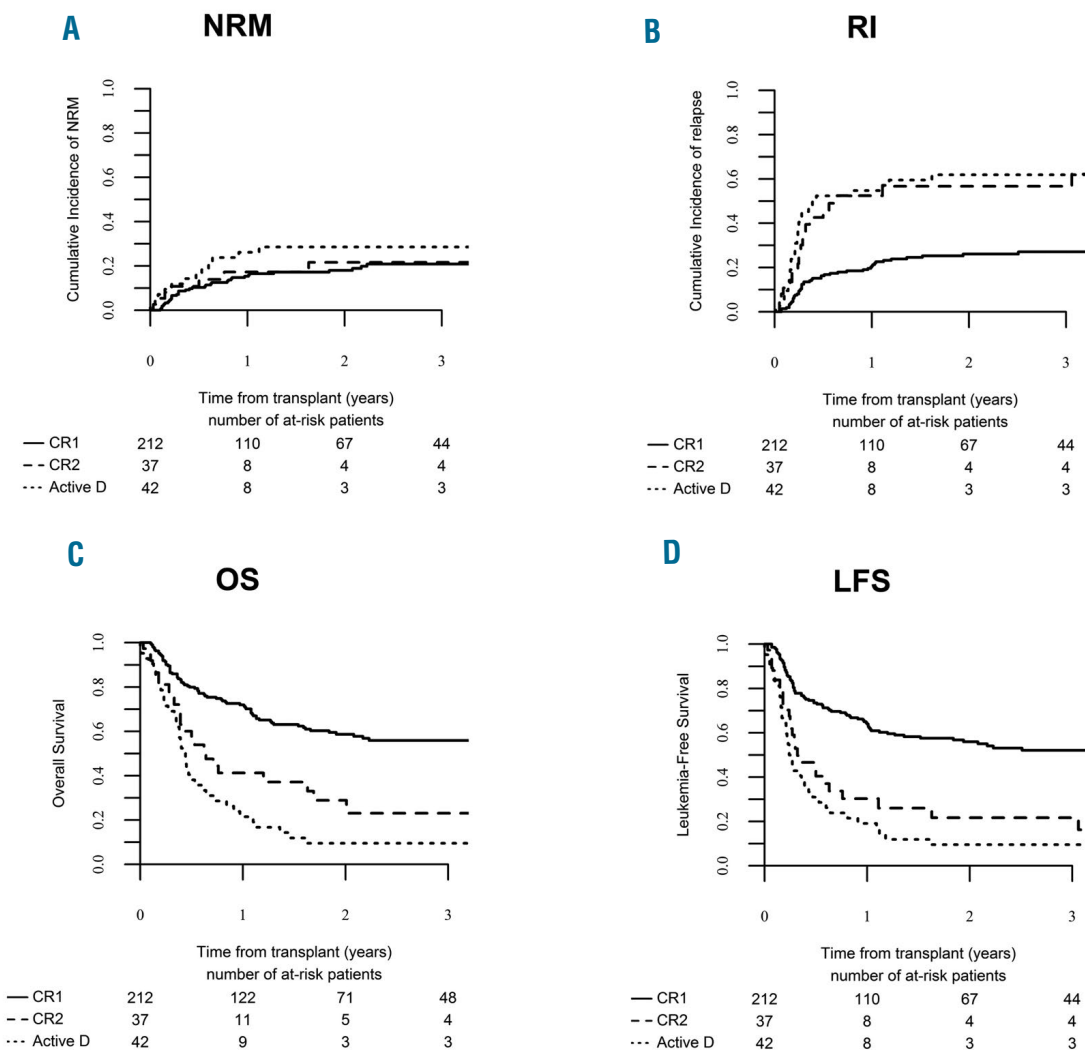
Among the 291 patients, the 2-year probability of OS was 46.7% (95% CI: 40.4-53.1). Disease status at SCT was the most powerful factor influencing survival, with a 2-year OS of 58.7% (95% CI: 51.2-66.1) in patients transplanted in CR1, 28.8% (95% CI: 12.3-45.4) in those transplanted in CR2, and only 9.5% (95% CI: 0.6-18.4) when transplantation was performed in active disease ( $P<0.001$ ) (Figure 2C). In multivariate analysis, only disease status at the time of SCT (CR2 and active disease compared to CR1) was significantly associated with decreased OS



**Figure 1. Cumulative incidence of chronic graft-versus-host disease (GvHD).** The 2-year cumulative incidence of chronic GvHD was 34% (95% CI: 28.4-40.5) in the entire cohort ( $N=291$ ).

( $P < 0.001$ ; Table 3). Chronic GvHD was not associated with OS (HR=1.14, 95% CI: 0.74-1.79,  $P=0.57$ ). In the cohort of CR1 patients, the 2-year probability of OS was 69.1% (95% CI: 58.9-79.4) in patients with an interval from diagnosis to CR1 of less than 42 days, and 54.9% (95% CI: 43.5-66.2) in patients with a longer interval to diagnosis of CR1 ( $P=0.06$ ). We also found that a donor age of more than 47 years old was significantly associated with improved OS ( $P=0.02$ ), however, donor's age was associated with donor type, being significantly older in HLA-identical siblings compared with unrelated donors (53 vs. 36 years old,  $P < 0.001$ ). When we compared the oldest sibling donors to the youngest unrelated donors according to median age in each group, we consistently found better OS with sibling donors, which confirms the stronger impact of donor type over donor's age. In multivariate analysis adjusted for patients' age, performance status, conditioning intensity, donor CMV status and

*in vivo* TCD, older sibling donors were still associated with better OS (HR=0.38,  $P=0.008$ ) compared to younger unrelated donors. Time from CR1 to SCT was significantly longer for the youngest unrelated donors (107 days, range: 9-198) compared to the oldest sibling donors (83 days, range: 13-186,  $P=0.04$ ). The 2-year probability of OS was 62.7% (95% CI: 52.2-73.2) after SCT from a sibling donor, 57.7% (95% CI: 46.3-69.1) after SCT from a 10/10 unrelated donor and 42.2% (95% CI: 17.4-67) after SCT from a 9/10 unrelated donor, respectively, but those differences did not reach statistical significance across groups ( $P=0.27$ ). Age ( $>$  or  $<$  65 years old), *NPM1* status, molecular status at SCT, KPS, conditioning intensity, donor CMV positivity, and TCD were not correlated with OS in univariate analysis. In multivariate analysis, increasing patient's age as a continuous variable was significantly associated with better OS (HR=0.89, 95% CI: 0.8-0.99,  $P=0.03$ ), and SCT from 9/10 unrelated donors compared



**Figure 2. Non-relapse mortality (NRM), relapse incidence (RI), overall survival (OS) and leukemia-free survival (LFS) per disease status (first complete remission (CR1), second remission (CR2) and active disease (Active D)).** (A) The 2-year cumulative incidence of NRM was 18% (95% CI: 12.8-23.9) in CR1 patients, 21.6% (95% CI: 8.9-37.9) in CR2 patients and 28.6% (95% CI: 15.6-43) in Active D patients. (B) The 2-year cumulative incidence of relapse was 26.1% (95% CI: 19.9-32.6) in CR1 patients, 56.8% (95% CI: 37.1-72.3) in CR2 patients and 61.9% (95% CI: 44.9-75) in Active D patients. (C) The 2-year probability of OS was 58.7% (95% CI: 51.2-66.1) in CR1 patients, 28.8% (95% CI: 12.3-45.4) and 9.5% (95% CI: 0.6-18.4) in Active D patients. (D) The 2-year probability of LFS was 55.9% (95% CI: 48.6-63.3) in CR1 patients, 21.6% (95% CI: 6.4-36.8) and 9.5% (95% CI: 0.6-18.4).

to sibling donors showed a trend toward worse OS ( $P=0.09$ ) (Table 4).

The 2-year probability of LFS was 44.3% (95% CI: 38.1-50.5) for the whole patient cohort. Disease status had the strongest impact on LFS, with a 2-year LFS of 55.9% (95% CI: 48.6-63.3) in patients transplanted in CR1, 21.6% (95% CI: 6.4-36.8) if transplanted in CR2 and 9.5% (95% CI: 0.6-18.4) in patients not in CR at the time of SCT ( $P<0.001$ ) (Figure 2D). In multivariate analysis, the significant influence of disease status at SCT was confirmed ( $P<0.001$ ), and donor CMV positivity was also significant-

ly associated with worse LFS ( $P=0.04$ ) (Table 3). Chronic GvHD did not correlate with LFS (HR=1.51, 95% CI: 0.92-2.48,  $P=0.1$ ). In the cohort of patients transplanted in CR1, an interval from diagnosis to CR1 of less than 42 days was significantly associated with better LFS (64.6% vs. 52.5%,  $P=0.03$ ). On the contrary, other variables such as age ( $>$  or  $<$  65 years old), *NPM1* status, TCD, donor CMV positivity or conditioning intensity did not show a prognostic impact on LFS. Similarly to OS, we observed a better LFS in SCT from donors aged over 47 years old in univariate ( $P=0.02$ ) and multivariate analysis ( $P=0.01$ ). The 2-year

**Table 3.** Multivariate analysis using a Cox proportional hazards model, N=291. Shown are variables with  $P<0.15$  in univariate analysis. Non-relapse mortality, relapse incidence, overall survival and leukemia-free survival.

		P	HR	95% CI
NRM	Age (per year)	0.57	0.97	0.89
	Status at SCT (CR1 as reference)			
	CR2	0.36	1.55	0.61
	Advanced	0.02	2.38	1.17
	Type of donor (MSD as reference)			
	10/10 UD	0.06	1.85	0.97
	9/10 UD	0.11	2.02	0.85
	Karnofsky $>$ 90%	0.15	0.66	0.37
	RIC	0.39	0.75	0.38
	Donor CMV+	0.07	1.76	0.95
	<i>In vivo</i> TCD	0.90	1.04	0.56
RI	Age (per year)	0.23	0.96	0.89
	Status at SCT (CR1 as reference)			
	CR2	0.00001	4.59	2.37
	Advanced	$<0.00001$	4.23	2.42
	Type of donor (MSD as reference)			
	10/10 UD	0.81	0.94	0.56
	9/10 UD	0.68	0.86	0.41
	Karnofsky $>$ 90%	0.72	1.10	0.67
	RIC	0.63	1.16	0.64
	Donor CMV+	0.21	1.37	0.84
	<i>In vivo</i> TCD	0.15	0.71	0.44
OS	Age (per year)	0.31	0.97	0.91
	Status at SCT (CR1 as reference)			
	CR2	0.0004	2.64	1.53
	Advanced	$<0.00001$	3.35	2.13
	Type of donor (MSD as reference)			
	10/10 UD	0.17	1.34	0.88
	9/10 UD	0.26	1.40	0.79
	Karnofsky $>$ 90%	0.41	0.85	0.58
	RIC	0.53	1.16	0.72
	Donor CMV+	0.06	1.47	0.99
	<i>In vivo</i> TCD	0.43	0.85	0.58
LFS	Age (per year)	0.19	0.96	0.91
	Status at SCT (CR1 as reference)			
	CR2	0.00004	3.04	1.79
	Advanced	$<0.00001$	3.30	2.13
	Type of donor (MSD as reference)			
	10/10 UD	0.31	1.23	0.83
	9/10 UD	0.51	1.21	0.69
	Karnofsky $>$ 90%	0.51	0.89	0.61
	RIC	0.87	0.97	0.62
	Donor CMV+	0.04	1.51	1.03
	<i>In vivo</i> TCD	0.28	0.82	0.56

N: number; NRM: non-relapse mortality; RI: relapse incidence; OS: overall survival; LFS: leukemia-free survival; HR: hazard ratio; CI: confidence interval; SCT: stem cell transplantation; CR1: first complete remission; CR2: second remission; UD: unrelated donor; MSD: matched sibling donor; CMV: cytomegalovirus; TCD: T-cell depletion; RIC: reduced-intensity conditioning.

probability of LFS was 62.7% (95% CI: 52.2-73.2) after SCT from a sibling donor, 57.7% (95% CI: 46.3-69.1) after SCT from a 10/10 unrelated donor, and 42.2% (95% CI: 17.4-67) after SCT from a 9/10 unrelated donor, respectively, however, as with OS, those differences did not reach significance ( $P=0.27$ ). In multivariate analysis, increasing patient's age as a continuous variable and a shorter interval from diagnosis to CR1 were both significantly associated with better LFS ( $P=0.03$  and  $P=0.05$ , respectively) (Table 4).

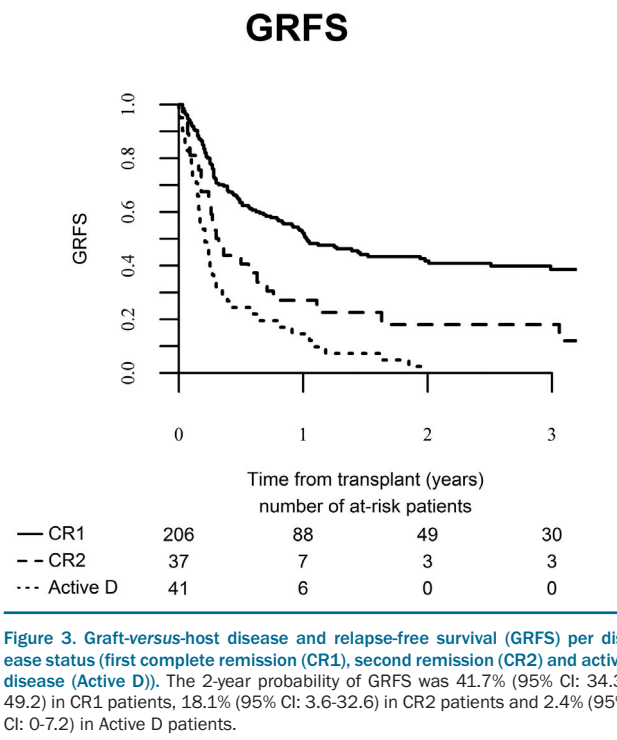
The 2-year probability of GRFS was 32.3% (95% CI: 26.3-38.3) in the study population. A worse GRFS was seen with more advanced disease; 41.7% (95% CI: 34.3-49.2) in patients transplanted in CR1, 18.1% (95% CI: 3.6-32.6) and 2.4% (95% CI: 0-7.2) in patients with CR2 and active disease at the time of SCT, respectively ( $P<0.001$ ) (Figure 3). Multivariate analysis performed on GRFS within the entire cohort and the CR1 patients is available in the *Online Supplementary Material*.

We also focused on the two main conditioning regimens within CR1 patients, which were fludarabine and busulfan ( $N=95$ ), followed by fludarabine and melphalan ( $N=30$ ). We found no significant differences in terms of acute and chronic GvHD incidence, NRM, RI, OS and LFS between those two regimens in univariate analysis (*data not shown*).

## Discussion

SCT is becoming a routine standard of care consolidation strategy for younger patients with AML and *FLT3*-ITD.<sup>3,8-11,23</sup> Nonetheless, its potential benefit for older patients has not been specifically addressed, and there is currently no strong evidence which supports SCT for elderly patients with *FLT3*-ITD AML.<sup>13,24</sup> Against this background, our study demonstrated that in patients with an age equal to or over 60 years old, SCT performed in CR1 translates into a 2-year OS and LFS of 59% and 56%, respectively. A NRM and RI rate of 18% and 25%, respectively, are acceptable in this population. Interestingly, these results are only slightly inferior than those reported in younger patients, and suggest the relevance of graft-versus-leukemia (GvL) for disease control in this entity.<sup>8,13,24</sup> Moreover, increasing age was not associated with NRM and other outcomes within our population, probably reflecting a careful and adequate selection process in the elderly AML population submitted to SCT in CR1. On the contrary, we found very poor outcomes when SCT was performed beyond CR1, thus, the benefit of SCT in these situations remains questionable. The inferior results obtained in CR2 patients are in accordance with previous publications.<sup>25,26</sup> Based on our sizable dataset, we strongly recommend that SCT is offered as the best consolidation strategy for eligible patients in early disease phase with AML and *FLT3*-ITD.<sup>27-29</sup>

It is possible that we have to concede a selection bias in our study, howbeit this bias supports the need for a thorough evaluation of each older candidate prior to SCT. We did not find any difference in characteristics between the youngest and oldest patients from our population, such as time from diagnosis to CR1, conditioning regimen, hematopoietic cell transplant co-morbidity index (HCT-CI) or KPS. The superior OS and LFS observed among the oldest patients of our study may be explained by individ-



**Figure 3. Graft-versus-host disease and relapse-free survival (GRFS) per disease status (first complete remission (CR1), second remission (CR2) and active disease (Active D)).** The 2-year probability of GRFS was 41.7% (95% CI: 34.3-49.2) in CR1 patients, 18.1% (95% CI: 3.6-32.6) in CR2 patients and 2.4% (95% CI: 0-7.2) in Active D patients.

ual characteristics not reported in the registry. KPS and HCT-CI are well-described tools used to evaluate patients before SCT, and are reliable even in older patients.<sup>15,17</sup> In addition to HCT-CI, other tools have been described in the assessment of elderly patients undergoing anti-leukemic therapy, and found that chronologic age is definitively not a limiting factor.<sup>16,30-32</sup> This assessment included the functional, cognitive, biological, nutritional and medical evaluation of each patient, and helped us to discern the best candidate for intensive therapy or SCT.<sup>33,34</sup>

*NPM1* mutation had no impact on any outcome parameter in this study. The favorable prognostic influence of *NPM1* has been demonstrated in patients of up to 65 years of age, although it is less pronounced or even lost in older subjects.<sup>35,36</sup> Several studies focused on younger patients have shown that *NPM1* mutation may influence OS and LFS in *FLT3*-ITD AML,<sup>37-39</sup> however, this impact is observed primarily in patients with a low allelic ratio of *FLT3*-ITD.<sup>37,39,40</sup> In *NPM1*-mutated AML, only patients harboring a high level of *FLT3*-ITD may benefit unequivocally from SCT.<sup>41-44</sup> Information regarding the *FLT3*-ITD allelic burden was not available in our study, and, given the lack of current standardization, it remains extremely difficult to analyze it in a multicenter registry setting.<sup>45</sup> Moreover, the concurrent mutation of DNMT3A, frequently found in combination with *FLT3*-ITD and *NPM1* mutation, may have a profound adverse prognostic impact, and the capacity for SCT to overcome this poor prognosis is currently unknown.<sup>2,46-48</sup> We also found that patients transplanted in molecular remission at the time of SCT had a better outcome after SCT, with a decreased relapse risk and a trend toward improved LFS and GRFS, a fact which has been recently addressed by Gaballa et al.<sup>49</sup> Nonetheless, the role of upfront SCT for patients who fail to achieve a molecular remission before SCT is unknown, and the benefit of donor lymphocyte infusion or other



**Table 4.** Multivariate analysis using a Cox proportional hazards model, N=212 (CR1 patients). Shown are variables with  $P < 0.15$  in univariate analysis. Non-relapse mortality, relapse incidence, overall survival and leukemia-free survival.

		P	HR	95% CI	
NRM	Age (per year)	0.15	0.88	0.75	1.05
	Type of donor (MSD as reference)				
	10/10 UD	0.42	1.46	0.58	3.68
	9/10 UD	0.03	3.58	1.15	11.13
	Kanofsky > 90%	0.10	0.52	0.23	1.14
	RIC	0.28	0.56	0.20	1.61
	Diagnosis to CR1 > 42 days	0.61	1.23	0.56	2.68
	CR1 to SCT > 98 days	0.04	2.50	1.06	5.91
RI	<i>In vivo</i> TCD	0.75	1.15	0.50	2.66
	Age (per year)	0.10	0.90	0.79	1.02
	Type of donor (MSD as reference)				
	10/10 UD	0.41	1.36	0.65	2.87
	9/10 UD	0.71	0.76	0.17	3.41
	Kanofsky > 90%	0.37	1.45	0.64	3.25
	RIC	0.77	1.18	0.40	3.48
	Diagnosis to CR1 > 42 days	0.02	2.32	1.15	4.70
OS	CR1 to SCT > 98 days	0.21	0.63	0.31	1.28
	<i>In vivo</i> TCD	0.06	0.53	0.27	1.04
	Age (per year)	0.03	0.89	0.80	0.99
	Type of donor (MSD as reference)				
	10/10 UD	0.29	1.39	0.76	2.54
	9/10 UD	0.10	2.14	0.88	5.23
	Kanofsky > 90%	0.52	0.83	0.47	1.47
	RIC	0.87	0.94	0.43	2.06
LFS	Diagnosis to CR1 > 42 days	0.16	1.47	0.86	2.52
	CR1 to SCT > 98 days	0.71	1.11	0.64	1.93
	<i>In vivo</i> TCD	0.36	0.78	0.45	1.34
	Age (per year)	0.03	0.89	0.80	0.99
	Type of donor (MSD as reference)				
	10/10 UD	0.29	1.36	0.77	2.42
	9/10 UD	0.13	1.9	0.82	4.40
	Kanofsky > 90%	0.73	0.91	0.52	1.57
	RIC	0.64	0.84	0.40	1.75
	Diagnosis to CR1 > 42 days	0.05	1.67	1.02	2.79
	CR1 to SCT > 98 days	0.59	1.15	0.69	1.93
	<i>In vivo</i> TCD	0.25	0.74	0.44	1.23

N: number; NRM: non-relapse mortality; RI: relapse incidence; OS: overall survival; LFS: leukemia-free survival; HR: hazard ratio; CI: confidence interval; CR1: first complete remission; UD: unrelated donor; MSD: matched sibling donor; RIC: reduced-intensity conditioning; TCD: T-cell depletion.

maintenance therapy in this setting should be specifically addressed in future studies.

A relevant issue concerning *FLT3*-ITD AML is the potential benefit of the use of *FLT3* inhibitors in combination with intensive chemotherapy in patients undergoing SCT. In this regard, the addition of midostaurin to chemotherapy in newly diagnosed *FLT3*-ITD AML has been showed to significantly improve survival, even in patients undergoing SCT in CR1, suggesting that a deeper anti-leukemic response before SCT can translate into an improved outcome after transplant.<sup>50</sup> Since information on the use of *FLT3* inhibitors pre- and post-transplant was not available in this registry study, we were unable to specifically analyze their effects. The prevention of relapse after SCT<sup>8,13</sup> with post-transplant maintenance therapy based on *FLT3* inhibitors is an area of current preferential interest, and is being investigated *via* ongoing clinical trials using agents such as sorafenib, midostaurin or gilteritinib. Small retrospective studies on maintenance with sorafenib have resulted in reduced RI and improved survival with-

out increased toxicity.<sup>51-54</sup> Nevertheless, SCT remains the best consolidation therapy offered to date, and the use of *FLT3* inhibitors may only increase the proportion of patients, including frailer subjects, who might benefit from SCT.

Herein, transplantation from 9/10 unrelated donors was associated with significant higher NRM and a trend toward inferior OS and LFS compared to sibling donors and 10/10 unrelated donors, as previously reported.<sup>55,56</sup> However, an unrelated donor may be preferable due to the fact that older patients have older sibling donors, and donor age has been associated with decreased survival due to an excess of acute and chronic GvHD.<sup>57</sup> Of note, improved survival has been observed with the use of younger unrelated donors compared to older sibling donors in an EBMT retrospective study,<sup>58</sup> while another large study from the Center for International Blood and Marrow Transplant Research (CIBMTR) reported no difference in terms of outcomes between younger matched unrelated donors and older sibling donors.<sup>59</sup> Among our

CR1 patients, we found that older donor age (>47 years old) was associated with more chronic GvHD, but better OS and LFS, and had no effect on RI. However, the age of the donor was strongly associated with the type of donor. The effect of donor type on outcomes was more potent than that of donor age, and our observations favor the use of a sibling donor, if eligible for stem cell donation. If a sibling donor is not available, a 10/10 fully matched unrelated donor is a suitable option, but caution must be applied with the use of a 9/10 unrelated donor. Nevertheless, we found a shorter interval from CR1 to SCT with sibling donors compared to older donors. We suggest an early donor search in order to further improve the results obtained with unrelated donors. TCD was significantly

associated with less chronic GvHD and less extensive chronic GvHD, with no effect on OS and LFS. We did not find a beneficial effect of chronic GvHD on RI and LFS to support the existence of a GvL effect in our population.

In conclusion, SCT emerges as a recommended consolidation strategy for fit patients aged 60 or over with AML and FLT3-ITD in CR1. Based on our study, and in view of the inferior results observed when SCT is performed in CR2 and beyond, we do not recommend postponing SCT until relapse. However, the few patients over 70 years of age included herein preclude firm recommendations for older patients. Sibling donors or fully matched unrelated donors remain the best donor choice in this older population.

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